



Advanced Microturbine Program Capstone Turbine Corp. Matthew Stewart

DOE DE-FC02-00CH11058
Debbie Haught – Program Manager
DER Peer Review
Washington, D.C., December 2003

Agenda



- Requirements and Program Overview
- Status of Development
 - Rigs
 - Engine
 - Recuperator
 - Electronics and Balance of Plant
- Project Plan and Risks
- Summary

Requirements and Program Overview



- Goals per DOE solicitation
 - Efficiency: $> 40\%$
 - Cost: < 500 \$/kW
 - Life: > 11 k hours to overhaul, 45k service life
 - Multiple fuels
 - Emissions: < 7 ppm NO_x
- Capstone development plan
 - Complete development of microturbine that increases efficiency to mid 30%
 - Higher effectiveness recuperator
 - Advanced materials
 - Improved designs
 - Leverage strategic alliance with United Technologies to combine microturbine and Organic Rankine Cycle for high efficiency microturbine system
 - High efficiency system to meet all DOE solicitation goals

Major Efforts



- Task 1
 - Preliminary design
 - Rig design
 - Ceramic feasibility
 - Preliminary recuperator design
 - Subtask A
- Task 2
 - Detailed recuperator design
 - Recuperator process development
 - Ceramic process development
- Task 3
 - Power electronics and software
 - Remainder of plant (fuel system, test package)
 - Subtask B
- Task 4
 - Detailed microturbine design
 - Microturbine integration and test
 - Integration with UTC ORC
 - Report on development

Major Team Members



- Commercial partners
 - United Technologies: Thermally activated power systems
 - JH Benedict: Recuperator process development
 - COI Ceramics: Combustor material development
 - Weldmac: Engine component development
 - Onsite Energy: Marketing studies
- Government and Universities
 - ORNL: Material development and testing
 - UC Irvine: Combustion development

Rig Development

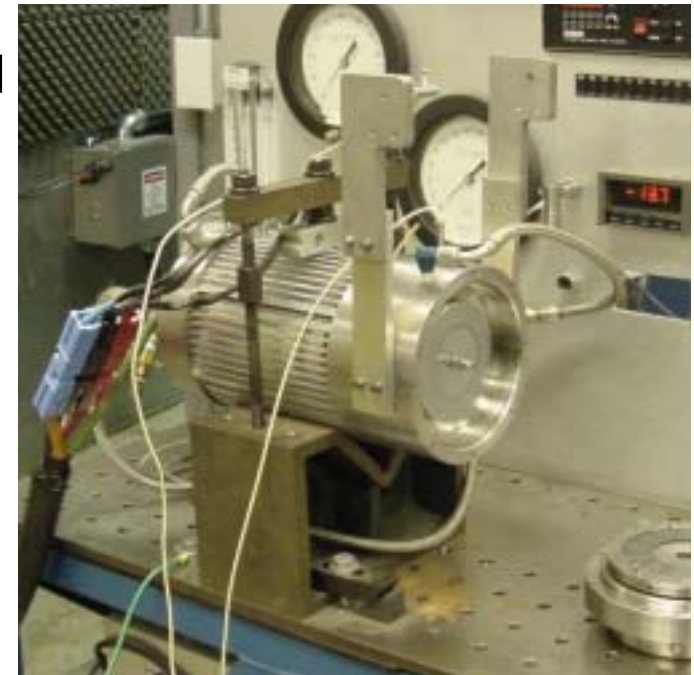
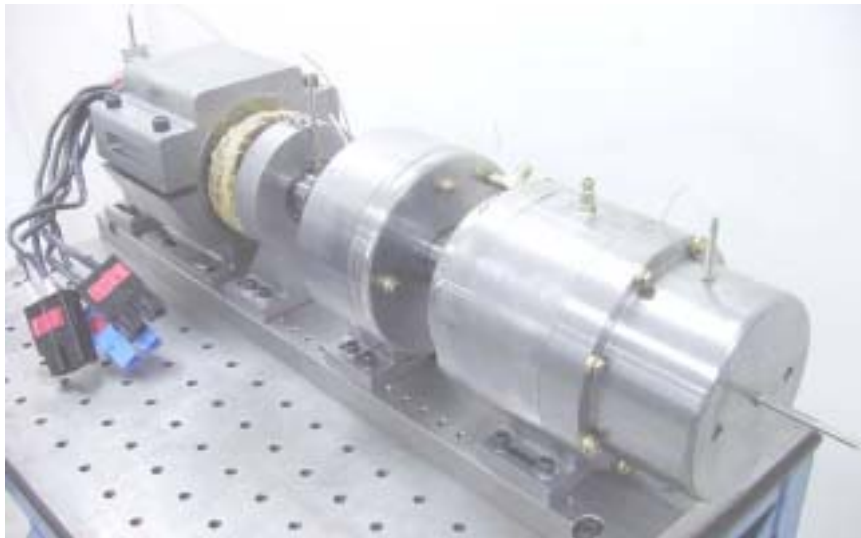


- Various rigs used throughout development
 - Rotordynamic and bearings
 - Combustor
 - Compressor
 - Recuperator
- Beneficial to program
 - Decrease development time
 - Focus on individual components or small subsystems
 - Maximize/optimize performance
 - Reduce project risk

Rotordynamic and Bearing Rigs



- Rotordynamic rig used to verify analysis and measure unbalance response
 - Uses full-scale engine hardware except aero-components
- Bearing rigs measure load capacity and power consumption
 - Optimize components
 - Thrust rig (shown)
 - Radial rig



Combustor Rig



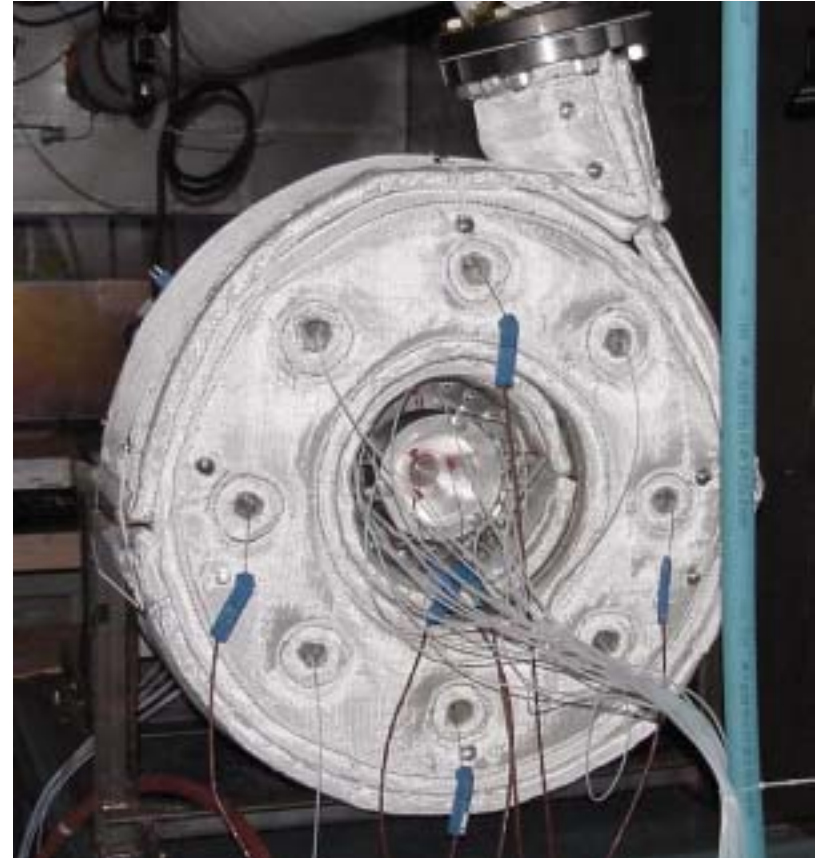
- Provides heated air to full scale combustor
- Increased accessibility for measurements
 - temperature, pattern factor, emissions
- Allows for easy modification



Compressor Rig



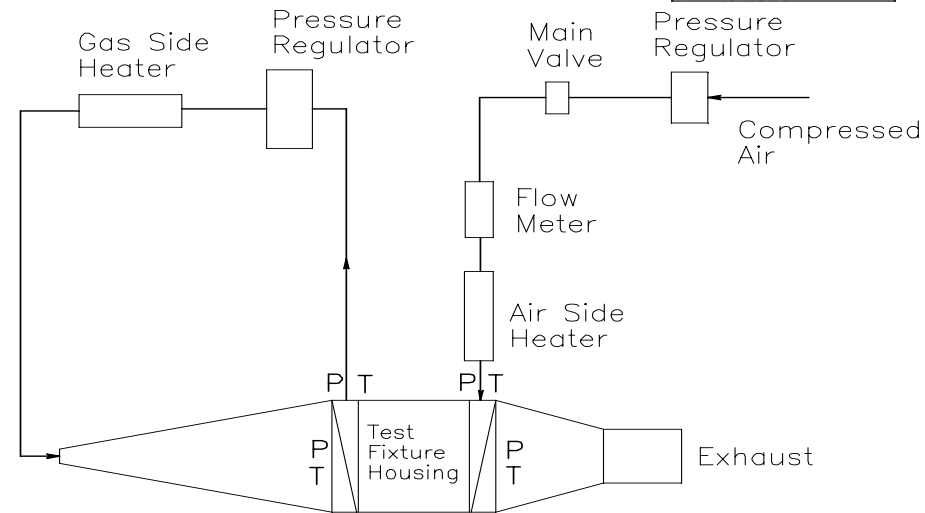
- Allows for development of compressor stage
- Confirm CFD models
- Greater access to temperatures and pressures
- Operate in surge and stall without risking engine hardware
- Determine the effect of inlet modifications



Recuperator Rig



- Test various full scale segments
 - Demonstrates manufacturing issues
- Allows independent control of inlet temperatures and pressures
- Verify CFD models
- Measures performance
 - Effectiveness
 - Pressure drop



Schematic of Recuperator Rig



Engine Design



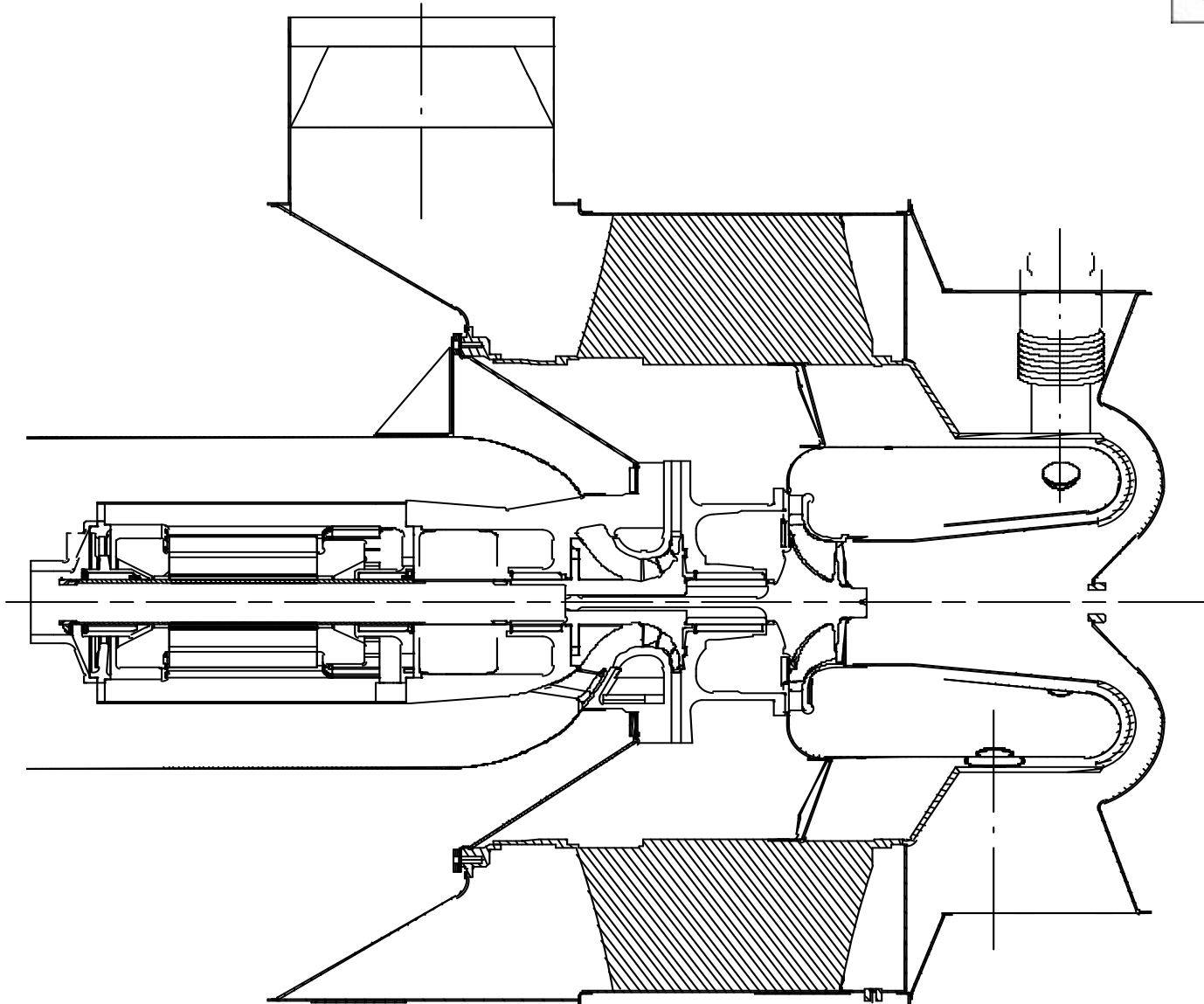
- Similar configuration to other Capstone engines
 - Single stage centrifugal compressor
 - Single stage radial inflow turbine
 - Single shaft for gas turbine and generator
 - Air bearings
 - No cooling or lubrication fluids
 - Low emission annular combustor
- Differences from previous Capstone systems
 - Greater focus on efficiency
 - Recuperator designed for greater effectiveness
 - Minimized losses
 - Solicitation cost targets and marketing studies were factors for determining platform rating
 - Designed to meet CARB 2003 emissions

Engine development



- Performance targets
 - 200 kW
 - >34% efficiency
 - <7 ppm NOx
- Cost targets
 - \$500/kW in production quantities
 - Designed for \$.005/kWh maintenance
 - Overhaul 40,000 hours
- Engine development timeline
 - Preliminary design 7/01
 - Started simple cycle engine testing 9/02
 - Started recuperated engine testing 12/03
 - Critical design 10/03

Engine Cross Section



Engine – Test Results to Date



- Engine testing to confirm design
 - Test fleet of 6 engines
 - Rotordynamic/bearings under thermal operating condition
 - Verify thermal model
 - All development issues addressed
- Endurance tests started
 - Demonstrated to date
>1000 hours
>1000 full power start cycles
 - One system doing multiple cold starts for bearing assessment
- Continued qualification underway



Rotordynamics and Bearings



- Rotordynamics
 - 200 kW engine is consistent with Capstone requirements
 - Rigid modes below operating range
 - Adequate margin above 100% speed to bending modes
- Bearings
 - Scaled from previous designs then optimized using rigs
 - 8 geometric parameters evaluated
 - Load capacity, power consumption and damping evaluated
 - Bearing loading within typical ranges
 - Engine thrust loads measured and acceptable

Performance



- Increased use of CFD as part of the design process
- Component efficiencies meet expectations
 - Verified in rig and engine testing
- Demonstrated >33% (fuel to electricity) efficiency in test cell – at ISO conditions
 - 5% points increase over previous designs
- Refinement/optimization underway to boost efficiency
 - Internal and external heat transfer
 - Secondary air system
 - Operating point

Recuperator



- Based on annular design
 - Substantial field experience with similar design
- Recuperator design for high effectiveness and low ΔP
 - Substantial improvement on system efficiency demonstrated
 - Developed with CFD and test rig
 - In addition to performance, focus on reliability and manufacturability
 - Qualification underway, with endurance testing
- Recuperator test results to date (from engine tests)

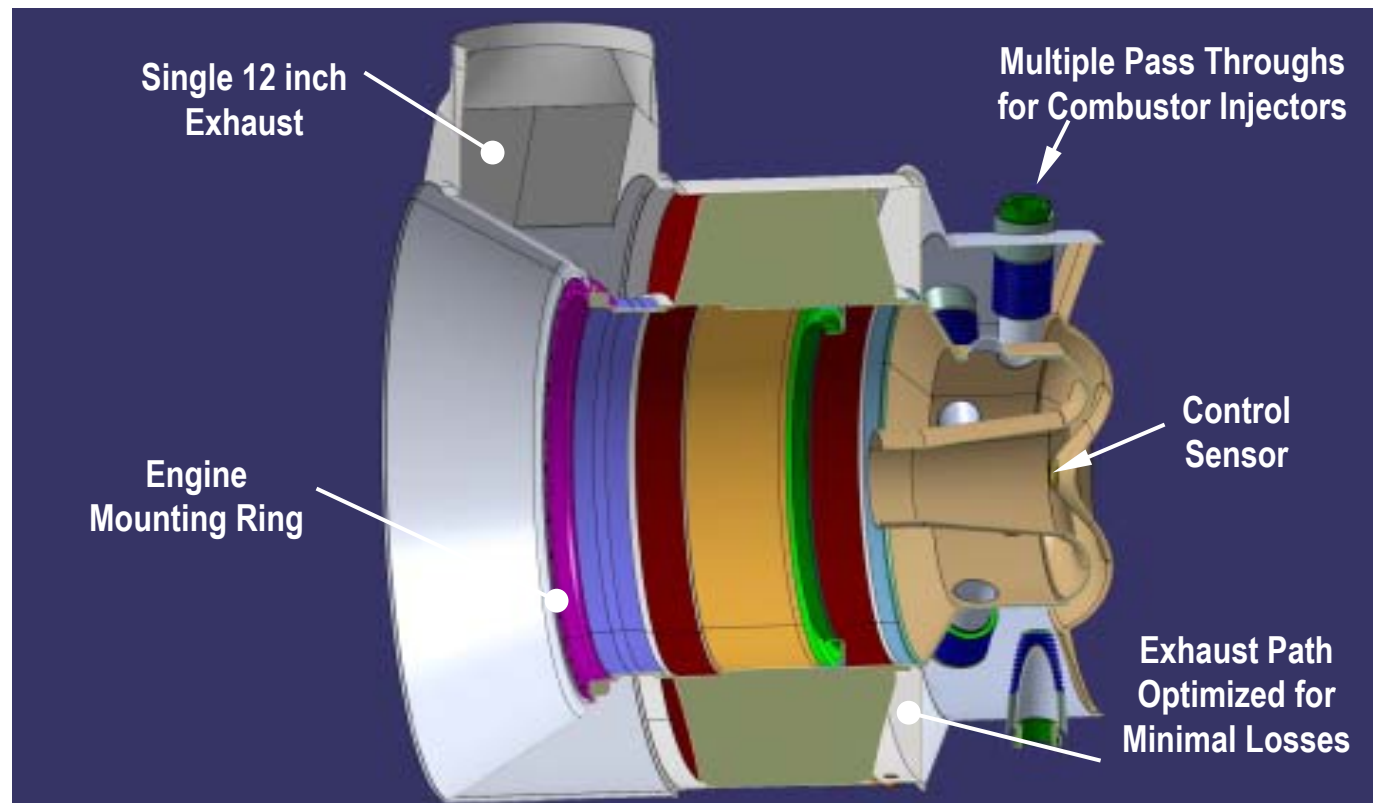


	Target	Test
Effectiveness [%]	89.7	89.0
Total Pressure Drop [%]	4.2	4.4

Recuperator Casing and Combustor



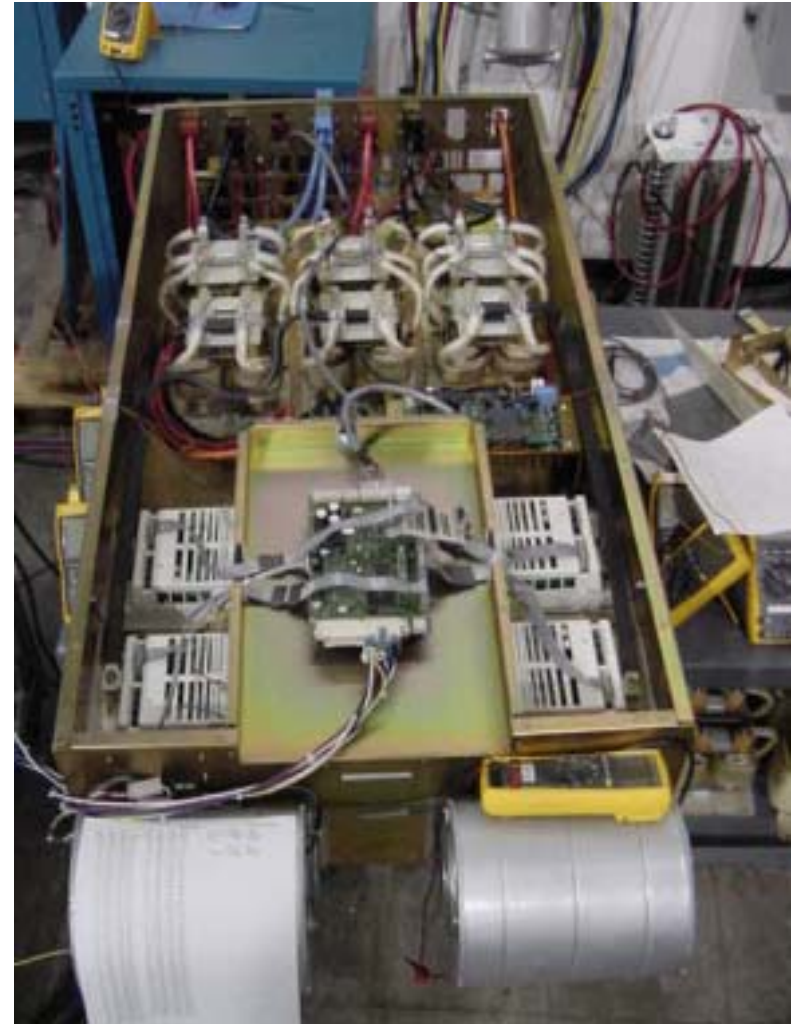
- Similar design method as previous systems
- High temperature alloys in hot section
- Lean pre-mix combustor with multiple planes to optimize emissions and stability
 - Demonstrated ability to meet CARB 2003 emissions



Power Electronics Development



- Tested to full power capacity
 - Satisfactory thermals
 - Air cooled (no liquids)
- Generator Control Module
 - Successfully starting and stopping C200 engine
- Load Control Module
 - Synchronized with grid
 - Regulated DC Bus

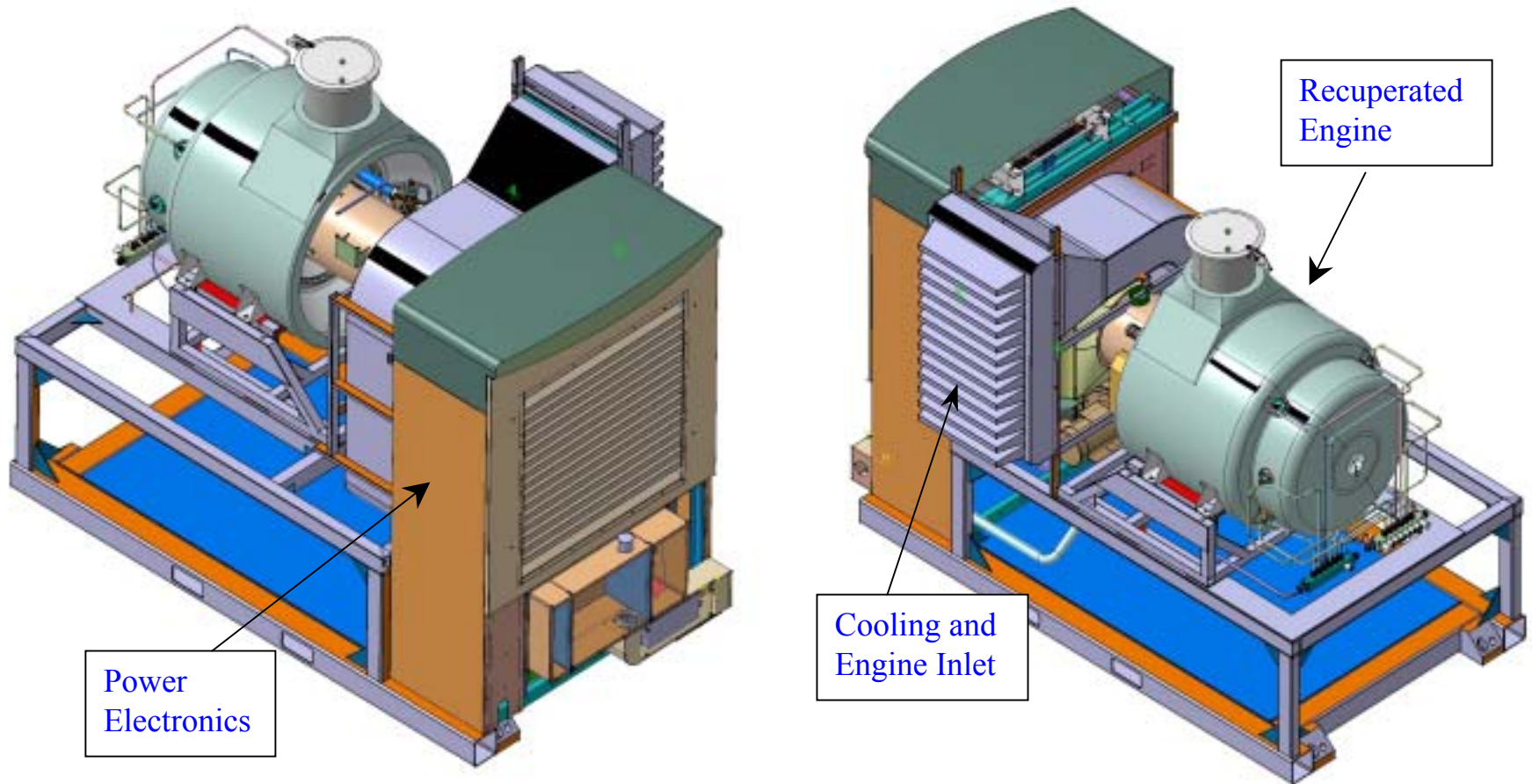


Fuel System and Package



- Fuel Control Valve
 - Outsourced to Woodward Governor
 - Currently used on all development engines
 - Gaseous system sized for wide BTU range
- Gas Compression
 - Include internal gas compressor in package
 - Working with compressor manufacturers on integrated system
- Package
 - Dimensions consistent with market requirements: 10' x 5.5' x 8' (L x W x H)
 - Three sides for maintenance (reduced footprint)
 - Air inlet from the side

Package Configuration



Primary Milestones to Date



- Project Kickoff
- Subtask A completed
- Engine Preliminary Design Review
- Subtask B completed
- Engine test initiated
- Receive first recuperator core
- Initiated recuperated engine testing
- Initiated endurance testing
- Motored C200 with power electronics
- Critical Design Review
- 11/2000
- 5/2001
- 7/2001
- 8/2002
- 9/2002
- 11/2002
- 12/2002
- 4/2003
- 9/2003
- 10/2003

Project Plan



- Planned milestones
 - Complete design refinement
 - Complete system qualification
 - System certification/compliance
 - Begin system Beta testing
 - Microturbine Pilot Product Release
 - Integration with UTC ORC
 - Complete project
 - Risks
 - Performance ~0.5% point less than target
 - Demonstrate life, limited endurance testing to date
 - System integration
- | |
|-----------|
| – Q4-2003 |
| – Q1-2004 |
| – Q1-2004 |
| – Q1-2004 |
| – 2004 |
| – 2004 |
| – 2005 |
- | |
|--------------------------------------|
| – Performance optimization |
| – Continued testing, multiple units |
| – Early testing with engine hardware |

Summary



- Project consistent with plan to develop an Advanced Microturbine System
- Greater than 5% points increase in efficiency demonstrated over existing designs
- Recuperator design improved system efficiency with high effectiveness and low pressure drop
- Combination with UTC ORC to meet solicitation goals
 - Low operating cost
 - Low first cost
 - Clean operation
- Commercial release planned – technology transfer
 - Available cost-effective distributed generation

Thank You

Questions